

# ADVANCED MODELING OF AIR- AND ROTORCRAFT IN A MULTI-DISCIPLINARY ENVIRONMENT AT EARLY DESIGN STAGES

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## **Abstract**

*The development of new air- and rotorcraft is very challenging. The design process is divided into three consecutive phases: Conceptual, preliminary and detailed design phase which combine various disciplines featuring different objectives, e.g. static versus crashworthy design.*

*This paper focuses on the preliminary design stage. The aim of the presented work is a significant reduction of the time spent on model generation in a multi-disciplinary design environment. Moreover, automation is desired to couple different disciplines respectively tools, hence, reducing the error probability compared to manual processing.*

*In the preliminary design phase a basic aircraft configuration which has been developed during the conceptual design serves to conduct trade studies. Objective of this stage is to enhance this basic aircraft configuration establishing an appropriate design that meets customer requirements including performance, weight, producibility and cost. This phase is of particular interest since the basic layout of the primary structure is defined here. Up to date, semi-analytical methods are commonly deployed during preliminary design. Though these methods lead to adequate results for major structural components, the evaluation of new aircraft configurations is still very challenging. One philosophy to improve preliminary design is to introduce the use of Finite Element Methods (FEM) at this early design stage benefitting from the constantly increasing computational power.*

*To efficiently use FEM, fast and easy model generation methods are required. These methods also need to have the ability to cope with the generation of alternative design concepts (e.g. blended wing body, compound helicopter). In order to accelerate and simplify these modeling processes, the standardized data format CPACS (Common Parameterized Aircraft Configuration Schema) is used in combination with automated modeling tools.*

*In this paper fully parameterized and automated process chains for the generation and analyses of air- and rotorcraft fuselage structures will be presented. The tools used within these processes will be introduced and basic applications will be shown to demonstrate the versatility, effectivity and the gain in efficiency. Applications range from initial distribution of primary structure over static analysis to evaluation of crashworthiness.*

## **1. Introduction**

Air- and rotorcraft design is a complex challenge which is usually subdivided into three consecutive design phases – the conceptual, the preliminary and the detailed design phase.

In the conceptual design phase global design aspects and mission requirements are taken into account as for instance payload and range. Additionally, geometric boundary conditions are top priority, e.g. the positioning of cut-outs for doors, the dimension of cargo compartment but also outer dimensions for maintenance in hangars. As the result of this first design stage a basic aircraft layout is developed.

During the subsequent preliminary design stage this basic layout serves as a base to conduct trade studies to identify the most balanced technical solution among a set of proposed viable solutions. Sizing and analysis steps are taken into account at this stage by introducing different disciplines turning this phase into a multi-disciplinary optimization (MDO). Objective of this design phase is to enhance the sketch from the conceptual design and to establish an appropriate aircraft design that meets all customer requirements such as weight, producibility and cost.

Finally, in the concluding detailed design phase, all details of the aircraft configuration, that has been developed during the preliminary design stage, are defined. Particular attention is spent on manufacturing aspects.

As detail level increases in each design phase each stage requires more parameters to be taken into account, thus, leading to more and more complex calculations. Up to date, semi-analytical methods are commonly deployed during preliminary design. Though these methods lead to adequate results for major structural components, the evaluation of new aircraft configurations is very challenging.

Increasing computational power allows and also justifies the intense use of Finite Element (FE) methods already during preliminary design. The efficient use of FE methods at this early stage, in turn, demands

fast and feasible generation of appropriate numerical models. Therefore, a high degree of parametrization and automation is desired. Moreover, model generation methods need to be designed flexible to allow the generation of alternative design concepts, e.g. blended wing aircraft or compound helicopter.

Due to the highly progressed design in the detailed design stage, changes during detailed design are very expensive and complicated to manage/handle. Thus, cost- and time intensive redesign at the detailed design stage may be prevented as parametrization allows the conduction of parameter variations in the preliminary design phase.

Automation becomes important as soon as parameter variations are conducted because they request the analysis and generation of numerous different, though similar, models. Hence, many similar work steps have to be carried out which might result in errors if conducted manually. Furthermore, computers are able to conduct certain work steps much faster and in a standardized, automated way. These tasks involve FE model generation, conduction of numerical simulations as well as post-processing of results. Interpretation of the results, however, is still considered as domain of the engineers involved.

Figure 1 shows a simplified scheme of the aircraft design process with particular attention to structural design.

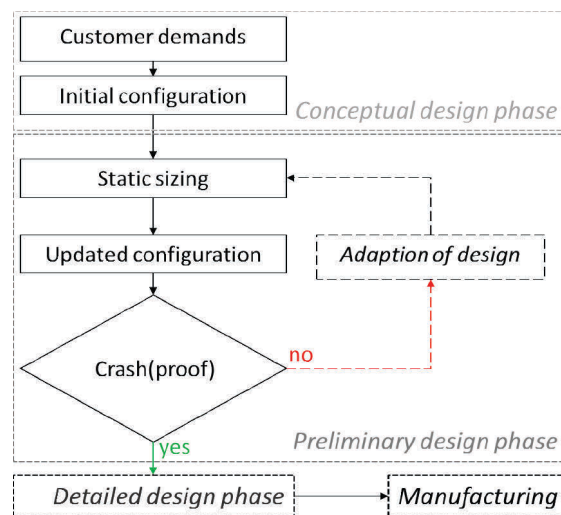


Figure 1: Aircraft design process (simplified)

This paper focuses on the preliminary design stage. Several tools for the structural analysis of air- and rotorcraft at this early design stage have been developed at the Institute of Structures and Design of the German Aerospace Center (DLR). These tools will be introduced in the

presented paper. The model generation process will be described and benefits of using these parametrized and automated tools will be illustrated. CPACS (Common Parametric Aircraft Configuration Schema) is used as central data format and will be briefly introduced highlighting its significance for the presented process chains. Finally, an outlook on future tool developments will be discussed.

## **2. Preliminary design stage**

The preliminary design phase is of particular importance as different disciplines are introduced and combined. Different disciplines feature different objectives, e.g. static versus crashworthy design: Static fuselage design calls for a comparably stiff airframe to carry global bending and torsion due to ground and flight loads, keeping deformations small. Crashworthy design, on the other hand, requires compliant behavior in case of survivable crash landings. In that case the kinetic impact energy can be absorbed by either plastification (metallic structures) or damage evolution (composite structures) in order to minimize resulting occupant accelerations. Objective of this design stage therefore is to find an optimum global solution for a specific problem by combining various disciplines. Thus, multi-disciplinary optimizations are nowadays state of the art.

As mentioned above, the preceding conceptual design phase ends with the generation of an initial aircraft configuration. Thus, the first task in preliminary design is to fill the given loft with primary structure, e.g. frames and stringers. Subsequently this initial configuration is statically sized according to specified ground and flight load cases.

Aviation authorities require a crashworthiness proof for certification of new aircraft. Therefore, the final aircraft configuration has to allow for sufficient energy absorption capability to keep resulting occupant accelerations survivable. Past has proven that crashworthiness aspects should already be taken into account at the preliminary design stage as focusing solely on static requirements may lead to an airframe that is unable to comply with the crashworthiness proof. Thus, altering the aircraft design becomes very expensive as changes at the highly progressed stage of detailed design are very expensive. Therefore, crashworthiness investigations at the preliminary design stage may identify negative influences on crashworthiness caused by too high stiffness of the airframe.

It shall be noted at this point that preliminary design comprises many other disciplines besides the structural analysis. However, this paper focuses on the structural analysis of the airframe.

### 3. Data management

To simplify data management in multi-disciplinary analyses and, thus, increasing efficiency it is useful to employ a common data format. Within DLR all aeronautical institutes use the common data format CPACS (Nagel et al., 2012) for multi-disciplinary analyses.

CPACS is a xml-based (Extensible Markup Language) data format used to describe the air transport system including air- and rotorcraft. Development of CPACS started in 2005 during the TIVA project (Technology Integration for the Virtual Aircraft). CPACS has been published open source and can be downloaded from its homepage (CPACS homepage, 2015).

It features a hierarchical structure which allows good data mapping – certain nodes of the CPACS file may be accessed without processing the complete file - while the ASCII representation (American Standard Code for Information Interchange) makes it easy to handle. Information can be inherited by linking of properties, thus, reducing redundancy while increasing readability and clarity. Moreover, file size is kept small which results in fast data access.

Another major advantage of CPACS is that it serves as central interface for the different analysis modules in a multi-disciplinary environment. Figure 2 shows two general approaches of how analysis modules may communicate in a multi-disciplinary environment. In the conventional approach (Figure 2, left) each tool directly communicates with any other tool, thus, a growing amount of involved analysis tools evokes a quadratic increase of required interfaces. For each interaction an interface has to be programmed and maintained resulting in a high amount of continuous work. The second approach (Figure 2, right) uses the centralized data format CPACS as common interface for the involved tools. Contrary to the traditional approach the increase of required tool interfaces is linear with CPACS.

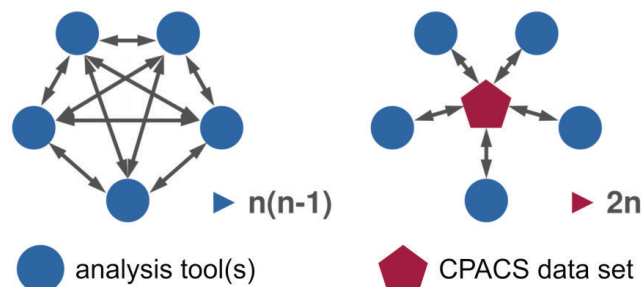


Figure 2: Tool interface schemes

Figure 3 illustrates the amount of required interfaces. Only for two tools the traditional approach requires fewer interfaces. If three tools are involved both approaches require the same amount of interfaces but as soon as four or more tools are involved, the CPACS approach requires fewer interfaces.

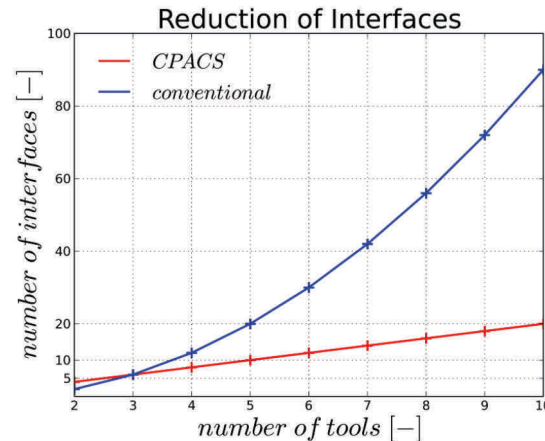


Figure 3: Reduction of tool interfaces with CPACS

In general, the reduction of required interfaces results in clearer process chains. Moreover, the programming and maintenance effort is significantly reduced. Data type errors are avoided by the use of one centralized data format. CPACS features a xsd file (XML Schema Definition) to validate datasets and respectively filter data input errors right from the start before analysis tools are initialized.

Within CPACS all relevant data for an aircraft configuration are stored. It contains global data to describe the aircraft as well as geometries, materials, flight missions, etc. Following, the definition of the fuselage geometry will be briefly introduced.

The fuselage loft geometry is represented by segments composed by fuselage profiles that describe the fuselage skin. Each fuselage profile is described by a discrete number  $n$  of profile points  $(P_1, \dots, P_n)$ . An exemplary description of a fuselage profile is illustrated in Figure 4 (note that only an arbitrary number of points is displayed). All points are located on a common plane at a given coordinate  $x$  in longitudinal direction and defined as denoted in the figure. The Cartesian coordinates  $y_i$  and  $z_i$  refer to the so-called aircraft reference axis.

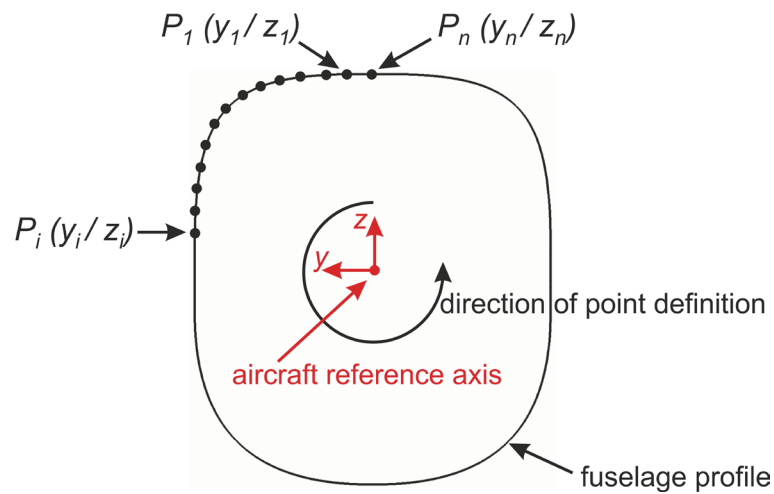


Figure 4: Generic fuselage profile definition

The fuselage profiles are connected via segments. An example of a segment formed by two fuselage profiles is given in Figure 5. The profiles are illustrated in black while the corresponding segment is highlighted in green. A non-dimensional value  $\eta$  runs from the front fuselage profile to the rear fuselage profile to account for each longitudinal position within any segment.

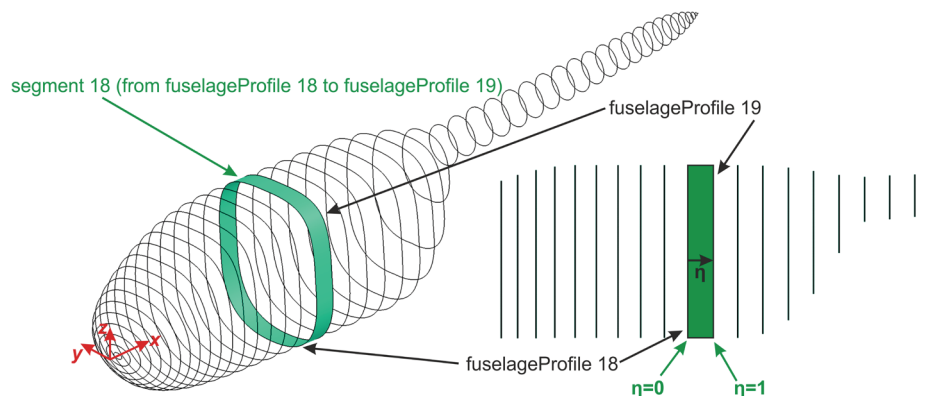


Figure 5: Fuselage profiles and segments as given in CPACS

By this means any arbitrary fuselage geometry can be defined within a CPACS file. To exemplarily show the versatility offered by CPACS, three generic rotorcraft fuselages are shown in Figure 6, comprising a transport helicopter with a tandem rotor configuration, a heavy transport helicopter and a light utility helicopter (seen from left to right).

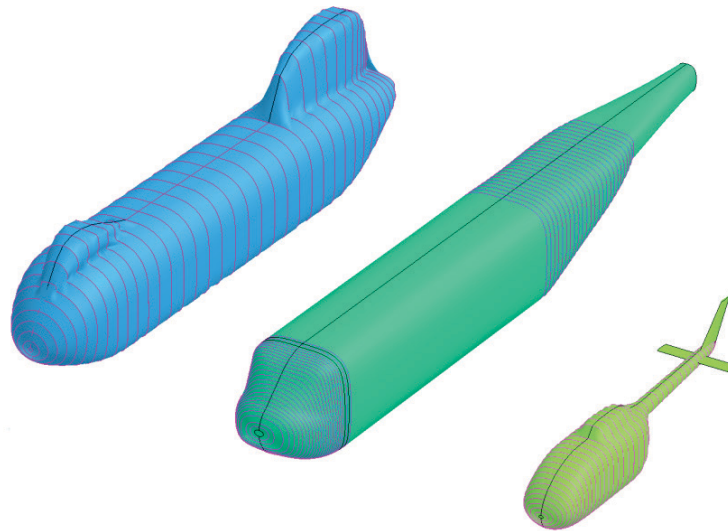


Figure 6: Generic helicopter lofts as basis for preliminary design

By changing the length of one (or more) segment(s) the fuselage may be stretched or shortened without changing any other parameters, e.g. the cross sectional area. The shortening of a generic heavy transport helicopter is exemplary shown in Figure 7. The length of the center fuselage segment is reduced from  $L_0$  to  $L_1$  as can be observed in the top and the isometric view. As the fuselage profiles themselves have not been changed the cross sections of both fuselage lofts remain unchanged (as can be seen in the front view).

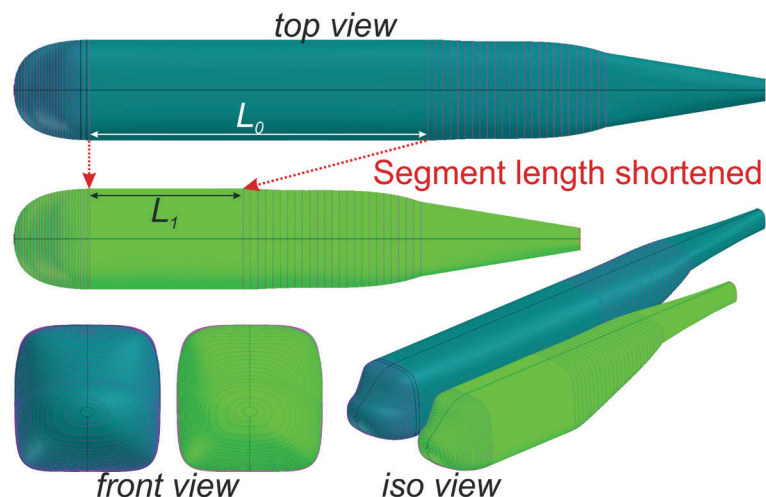


Figure 7: Stretching / Shortening of a fuselage segment

In a similar way structural reinforcements (e.g. frames, stringers) can be defined. CPACS features several alignment options for detailed



positioning of structural components (Scherer and Kohlgrüber, 2014; Schwinn et al., 2014).

Material data for the structural analysis of the airframe is defined within CPACS. Required parameters have to be defined respectively calculated by the user and stored in CPACS (e.g. Young's modulus, yield strength, plasticity behavior, etc.). Composite materials (lay-up and ply parameters) are supported by CPACS. Tool-specific information is also stored in CPACS to allow direct control of the corresponding tool (e.g. solver version).

In order to efficiently work with CPACS, the libraries TIXI and TIGL have been developed. They provide standardized routines to simplify the development of analysis modules reducing possible data misinterpretation:

- TIXI (TIXI XML Interface) is a library for input/output routines. It was developed to simplify the access to CPACS shielding the module developer from dealing with the complexities of xml structure handling.
- TIGL (TIXI Geometric Library) is a graphic library and was developed to easily process geometric information within CPACS.

TIXI and TIGL are available for download at their homepages (TIXI homepage, 2015; TIGL homepage, 2015). General information about CPACS as well as TIXI and TIGL is given by Bachmann (Bachmann et al., 2009). Though CPACS is used to describe both, air- and rotorcraft, it shall be noted that originally CPACS has been developed for the use with aircraft only. However, the use with rotorcraft has been initiated. Specific information about the use of CPACS regarding rotorcraft is given by Lier and Kunze (Lier et al., 2012; Kunze, 2013).

#### **4. Modeling and structural analysis tools**

This chapter introduces several tools developed at DLR-BT for the structural analysis of air- and rotorcraft fuselages. The applications range from static sizing to crashworthiness evaluation. Furthermore, basic approaches for the generation of numerical models will be presented.

In the previous chapter the definition of the fuselage loft was described. Frames and stringers are defined by a discrete number of position points. These points comprise a reference coordinate and a reference angle each. Figure 8 shows how these values are specified.

By this definition each point on the fuselage surface can be determined and its Cartesian coordinates calculated. In-house developed functions determine the segment number and the corresponding  $\eta$  value where an arbitrary x-position is located (see Figure 5). Another TIGL parameter to assess loft coordinates corresponds to a non-dimensional circumference value  $\xi$  and is also calculated by in-house functions. These values are used by TIGL functions for geometric calculations. Figure 8 shows the relationship between the reference values as defined in the CPACS file and the TIGL functions to calculate loft points. Note, that by placing a local coordinate system on the loft point, the derivative (normal vector) can be calculated to position structural components perpendicular to the fuselage surface. In the presented tools loft points used for surface generation are generated at each frame/stringer intersection. Typically, one frame and one stringer bay form a fuselage skin panel.

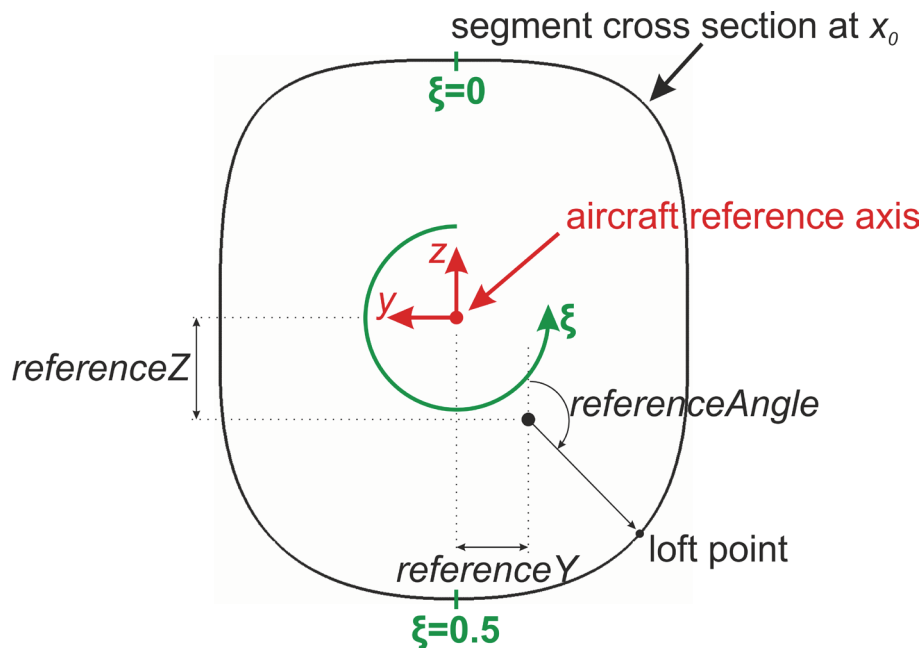


Figure 8: TIGL function to determine a point on a fuselage loft

These loft points can be used to place and position reinforcing structures (like frames and stringers) on the fuselage surface. Using the PROSHAPE toolbox (Harbig, 2010) input macros are written that are subsequently processed by ANSYS to generate the fuselage geometry. Automated meshing is subsequently conducted to generate FE meshes for structural analyses.

## F-DESIGN

As mentioned earlier, as the result from the conceptual design stage a fuselage loft is available. The first step in preliminary design stage, therefore, is to provide this loft with a primary structure by the use of certain knowledge based design rules.

F-DESIGN (Fuselage Design) is a tool that fills the loft derived from the conceptual design phase with primary structure. Frames and stringers are distributed within the fuselage. A first version of F-DESIGN distributed frames and stringers equally in longitudinal and circumferential direction while the current version allows for a more detailed positioning making use of extended design sets (Lier et al., 2014).

So-called design sets allow description of master frames and master stringers as well as definition of additional regions where structural members are distributed with changing pitches. Certain boundary conditions may affect structural placement and need to be taken into account, for instance positioning of door cut-outs. These sets are defined in the tool-specific node in the CPACS file. A design set comprises the definition of so-called main frames, main stringers and features the option to distribute the structure in detail. Various arbitrary designs with different frame and stringer distributions are depicted in Figure 9. The fuselage loft remained unchanged for all configurations. Note that, as the fuselage geometry is generated according to frame/stringer intersections, the meshes become more detailed the more stringers and frames are defined.

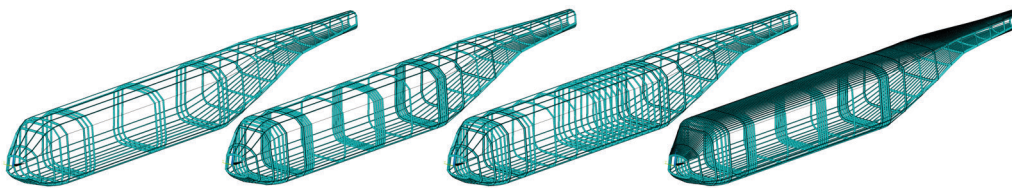


Figure 9: Various frame/stringer distribution within one generic rotorcraft

Recently, a new feature called *stage modeling* has been introduced. It allows a change of the stringer structural element (which is a profile with specified sheet thicknesses and material) along its extrusion path. Moreover, by setting the structural element parameter (in CPACS) of a reinforcing structure to *None*, this structure may be interrupted, thus, allowing cut-outs. Note that up-to-date this feature is implemented for stringers only. This feature is particularly interesting when dealing with structures on tapered lofts, e.g. stringers at the tail boom of a helicopter (see Figure 12) or at the rear section of a transport aircraft. This feature

may also be used to increase detail level of the structure by definition of dummy stringers. These stringers may be used to increase amount of frame/stringer intersection points but do not contribute to any stiffness.

### **Static analysis with TRAFUMO and ROFUMA**

For static analysis of transport aircraft the tool TRAFUMO (Transport Aircraft Fuselage Model) has been developed while the tool ROFUMA (Rotorcraft Fuselage Mass Assessment) has been developed for static evaluation of rotorcraft. As static load cases (e.g. pull up maneuvers, gust crossing) call for small deformations and linear elastic behavior, comparably coarse meshes of so-called GFEM (global FEM) quality are applicable. Static analyses are conducted using the ANSYS solver featuring an implicit time integration scheme.

The fuselage skin is discretized with shell elements (ANSYS Shell181) while the structural reinforcements are discretized with elastic beam elements (ANSYS Beam188) featuring arbitrary cross sections. By this means, the cross sections can be directly taken from CPACS without calculating any geometric properties (e.g. moments of inertia, cross-sectional area).

Additional masses (e.g. occupants, fuel, rotors, cargo, etc.) are modeled as single mass points being connected to the airframe by constraint equations (ANSYS RBE3).

External nodal loads (for instance main rotor lift) are transferred into the structure over a certain region to avoid high stress concentrations. The extent of this area can be specified by the user in the CPACS file.

TRAFUMO allows the optional coupling of fuselages to generic wing structures to introduce aerodynamic loads into the fuselage for sizing purposes. Wings and empennages are generated by the ELWIS tool (Finite Element Wing Structure). Aerodynamic loads are computed on the undeformed lifting surfaces using the tool AVLloads. More information on ELWIS and AVLloads is given in (Dorbath et al., 2012, 2013).

Figure 10 shows a short range (D150) and long range (D250) aircraft generated by TRAFUMO/ELWIS.

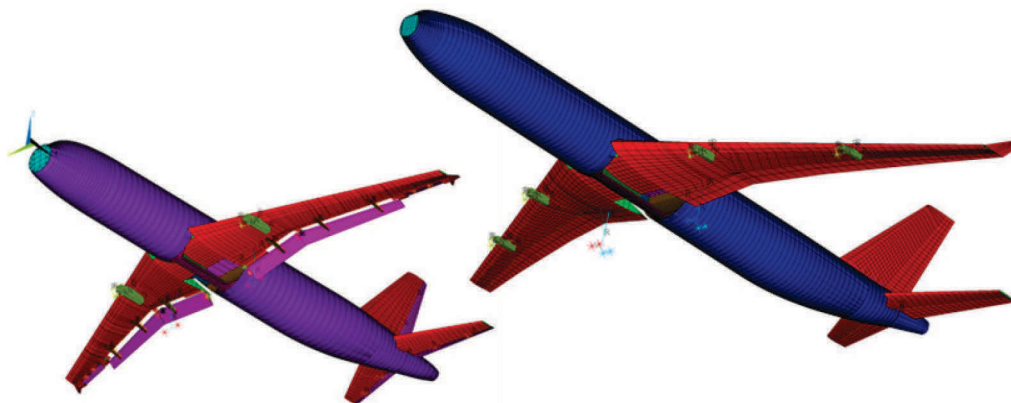


Figure 10: Short and long range aircraft (D150 and D250) (Schwinn et al., 2014)

Detailed information about the modeling of the center wing box area (including keel beam and main landing gear bay) and load introduction framework for the empennage structure in TRAFUMO is given by Scherer (Scherer et al., 2013; Scherer and Kohlgrüber, 2014).

ROFUMA is based on the same modeling techniques as TRAFUMO, though some features are not yet implemented, for instance coupling with wing structures. However, ROFUMA features some other options that have not yet been implemented in TRAFUMO and will be introduced subsequently.

Frames are discretized by the use of shell elements. Along their edges beam elements can be applied to account for any flanges as introduced by Hunter (Hunter, 2008). These beam elements can be provided with geometric and material data via CPACS. Using the ANSYS command `/ESHAPE` these sections can be visualized as shown in Figure 11.

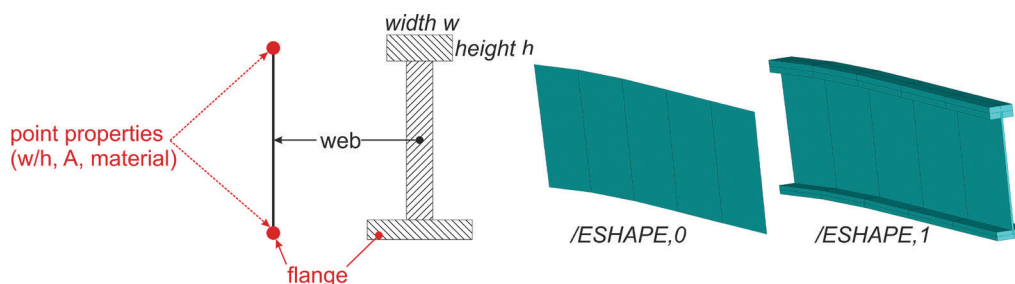


Figure 11: Mixed frame discretization

As already mentioned, stage modeling has been developed. This feature is implemented in ROFUMA and can be used to end or interrupt extrusion of structural elements along stringers (e.g. in case of cut-

outs). An example of a helicopter tail boom of a generic heavy transport helicopter is shown in Figure 12.

Without the use of stage modeling a given structural element that is placed on a stringer is extruded from the beginning of the stringer path until its end. This leads – in the example of the helicopter tail boom – to an excessive stiff and heavy structure. Note that – for visibility reasons – only one changing structural element is highlighted by the red circle in Figure 12.

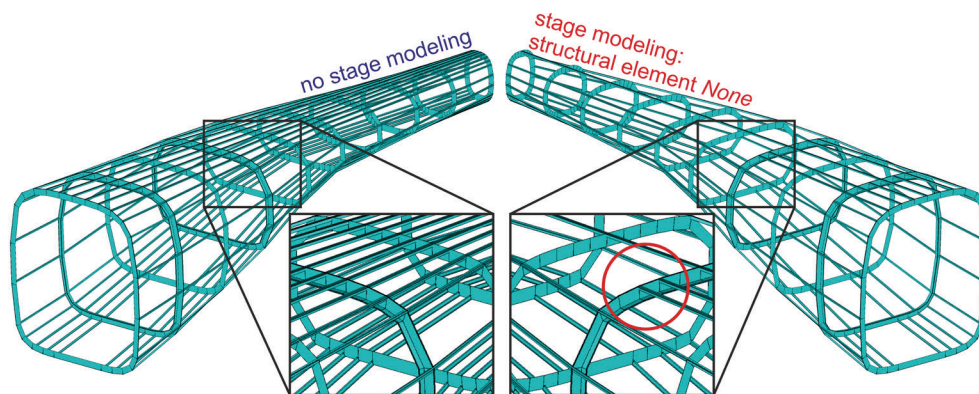


Figure 12: Stage modeling at helicopter tail boom structure

Figure 13 shows the reinforcing structure of a generic light utility helicopter and its nodal deformation (magnitude) due to a generic steady-state flight load case (the undeformed model is included in black and white). Displacements are shown amplified. As the model was clamped at the first frame, the deformation at the front is zero. The secondary mass is modeled using a single nodal mass located in the center of gravity. Thus, the region where the lift is introduced shows very little deformation while the forces generated by the tail rotor lead to bending and twisting of the tail boom.

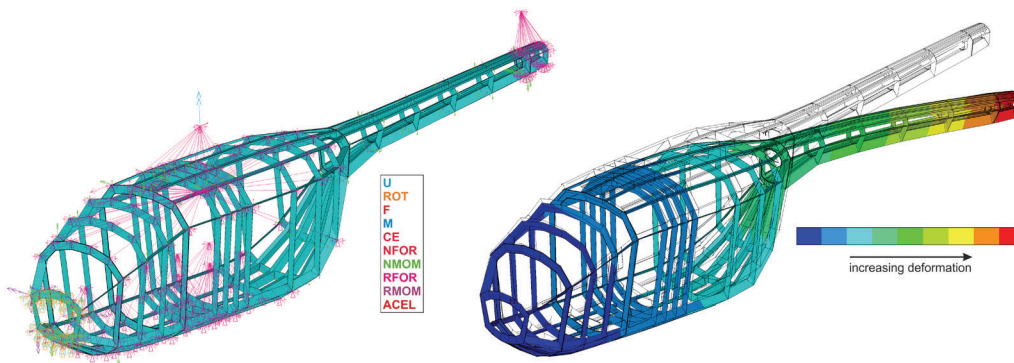


Figure 13: Light utility helicopter – FE model and displacements (magnitude)



## Static sizing with S-BOT+

Static sizing due to specified ground- and flight load cases is conducted using the optimization routine S-BOT+ (Sizing Robot+). It is an enhancement of the S-BOT tool which originally was developed at the DLR Institute of Composite Structures and Adaptive Systems for sizing of wing structures (Nagel et al., 2008).

The strength evaluation is based on a fully stressed design principle. The minimum sheet thickness is computed for each load case by the ratio of actual and maximum acceptable stress. After computation of all defined load cases the maximum required sheet thickness is stored for each element. By this means, an optimum material utilization can be guaranteed. More information about the sizing module S-BOT+ is given by Scherer (Scherer et al., 2013).

An exemplary result of a fuselage sizing process for a generic long range aircraft (D250) is shown in Figure 14. The highest skin thickness is located at the center wing box where high aerodynamic forces are transferred into the fuselage structure. Loads on the cockpit section in the front are very little, thus, the skin thickness in the front is very low. The fuselage model was clamped at the empennage structure leading to high reaction forces in this region resulting in comparably high skin thickness. Behind the mounting the required skin thickness is at minimum as no loads act.

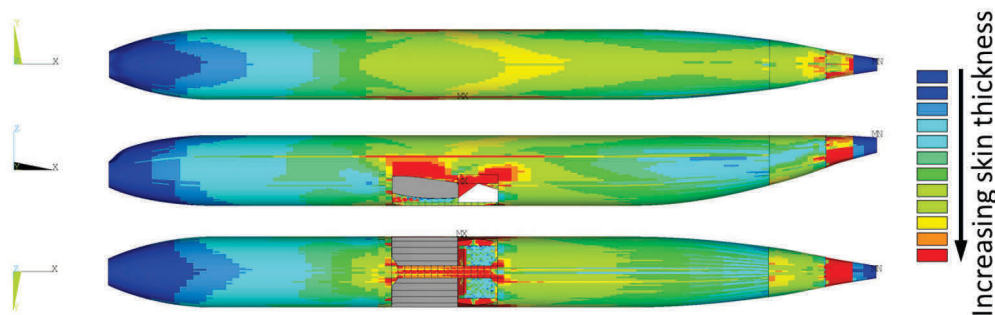


Figure 14: Sized fuselage of a generic long range aircraft (Schwinn et al., 2014)

S-BOT+ is currently only available for aircraft. Nevertheless, the implementation for rotorcraft structures has already begun and its completion is planned during 2015.

## Crashworthiness proof with AC-CRASH

For evaluation of crashworthiness aspects the tool AC-CRASH (Aircraft Crash) has been developed. The current version of AC-CRASH is

limited to aircraft fuselages. A new version is under development (X-CRASH) which will feature the crashworthiness analysis of rotorcraft as well. Examples presented in this paper show transport aircraft models for the analysis with VPS/PAM-CRASH.

Computations are conducted using the VPS/PAM-CRASH solver featuring an explicit time integration scheme. AC-CRASH offers refined discretization with small element sizes to account for non-linear structural behavior.

AC-CRASH features two different approaches depending on user specifications in the CPACS file: the generation and analysis of an aircraft section exposed to a vertical drop (Figure 15) and full fuselage crash scenarios with horizontal velocity component.

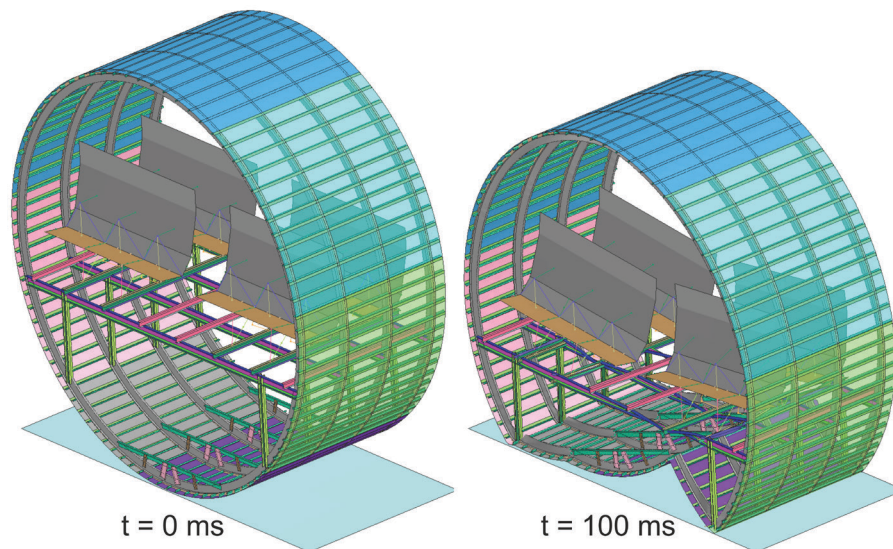


Figure 15: Vertical drop of a section of a short range aircraft (D150)

If the section approach is chosen, a section of user-specified length is generated and discretized by shell elements. In case the full fuselage approach is chosen a full fuselage is generated where the fuselage skin is discretized by shell elements while structural reinforcements (e.g. frames, stringers, etc.) are discretized by beam elements. So-called detailed regions (zones of high interest, for instance the first impact zone where the kinetic energy is induced into the fuselage) can be discretized by the use of shell elements with refined mesh size. Interfaces are automatically detected and the corresponding nodes are coupled in all six degrees of freedom by MTOCO (Multiple Nodes To One Node Constraint) elements in VPS/PAM-CRASH. Transition zones can be defined around detailed regions to stepwise increase element sizes. This approach provides a smooth mesh transition and with



suitable mesh gradients which ensures higher accuracy and, thus, avoids numerical instabilities during explicit analysis.

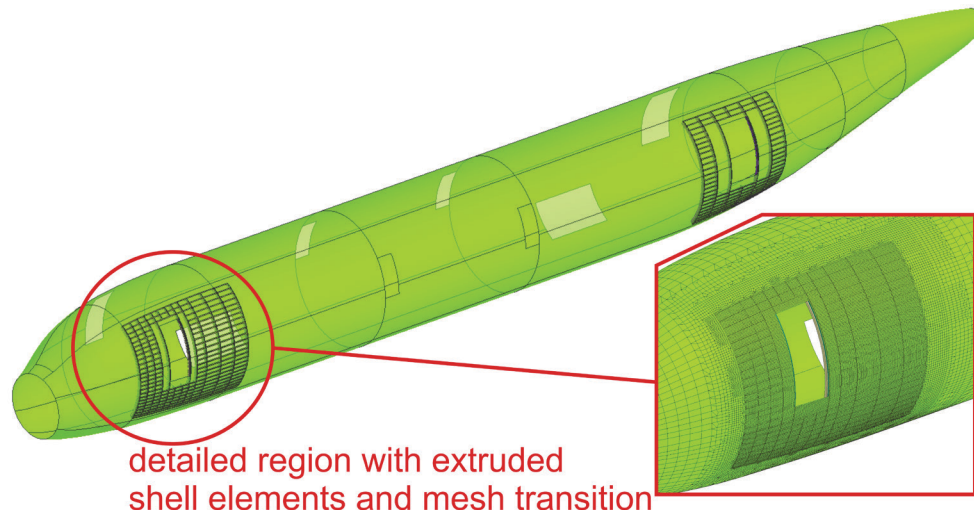


Figure 16: D150 fuselage with detailed region at front passenger door

A brief analysis of a generic full fuselage crash is described in (Schwinn, 2014). For more information about modeling options in AC-CRASH (detailed regions, occupant modeling, crashworthiness analysis) please refer to (Schwinn et al., 2012, 2013, 2014; Schwinn, 2014).

## 5. Benchmarking

This chapter provides a benchmarking of the model generation process using ROFUMA and AC-CRASH. Benchmarking was conducted using a Fujitsu Celsius W280 computer with following properties:

- Windows 7 (64bit), Enterprise Edition, Service Pack 1
- Intel® Core™ i7 CPU 870@2.93GHz
- 8GB RAM
- 4 processor cores
- NVIDIA Quadro 2000 graphic card with 1024 MB memory
- ANSYS 14.5

The times required for the model generation are shown in Table 1 and Table 2. Table 1 shows the times required for the generation of rotorcraft fuselages with ROFUMA while Table 2 shows the required

times for model generation of transport aircraft with AC-CRASH. The times given in these tables correspond to geometry generation respectively geometry and mesh. Note that required input cards (e.g. materials, boundary conditions, loads, etc.) are not included in this benchmarking.

**Table 1: Model generation benchmarking (ROFUMA)**

model	components	length [m]	nodes	elements	time
1.1	36	8.8	---	---	00:00:50
1.2	36	8.8	699	783	00:00:51
2.1	56	8.8	---	---	00:01:22
2.2	56	8.8	1,395	1,481	00:01:23
3.1	62	20.25	---	---	00:02:42
3.2	62	20.25	1,788	2,165	00:02:43
4.1	77	15.25	---	---	00:05:03
4.2	77	15.25	4,055	4,762	00:05:05
5.1	81	20.25	---	---	00:05:49
5.2	81	20.25	4,619	5,326	00:05:51

**Table 2: Model generation benchmarking (AC-CRASH)**

model	components	length [m]	nodes	elements	time
6.1	95	1.0	---	---	00:01:30
6.2	95	1.0	310,685	294,768	00:03:06
6.3	95	1.0	54,011	46,890	00:01:33
7.1	138	1.8	---	---	00:01:52
7.2	138	1.8	655,452	623,824	00:05:13
8.1	191	5.0	---	---	00:03:34
8.2	191	5.0	1,583,769	1,505,547	00:17:09
8.3	191	5.0	269,213	235,898	00:04:07
9.1	318	9.0	---	---	00:10:19
9.2	318	9.0	3,639,177	3,529,821	01:23:58
9.3	318	9.0	565,695	499,175	00:11:01
10.1	882	37.5	---	---	00:22:51
10.2	882	37.5	544,916	518,388	00:25:20

Models 1.1 – 2.2 correspond to the light utility helicopter as shown before. Models 3.1 – 5.2 correspond to versions of the generic transport helicopter that was introduced before. Models 4.1 and 4.2 represent a shortened version of that helicopter as indicated in Figure 7. It can be observed that model generation time depends on the amount of

structural components that have to be generated. However, the dimensions of the components do also have an influence, though marginal. Mesh generation takes about 2 seconds for about 5,000 nodes and elements.

Models 6.1 – 9.3 correspond to section models of a generic short range transport aircraft except models 10.1 and 10.2 which represent the full fuselage model.

Times for model generation range from about 90 seconds up to about 84 minutes for a very fine discretization with about 3,600,000 nodes and 3,500,000 elements. To show the dependency on mesh generation, some models were generated with two different element sizes as can be observed by the different amount of nodes and elements.

Due to the very fine discretization required for explicit FE analysis the amount of nodes and elements is higher than for the implicit models given in Table 1. Therefore, mesh generation requires significantly more time. Still, the geometry generation itself does not require more than 23 minutes for a full fuselage model of 37.5 m length. Comparing geometry generation of models 4 and 5 with models 6 and 7 it can be observed that the amount of components is not only responsible for the generation runtime. As the components of models 4 and 5 are much longer than models 6 and 7 they require more time. Figure 17 visualizes benchmarking from Table 1 and Table 2. Note that, due to visibility reasons, the models 9.2, 10.1 and 10.2 are not included in the figure.

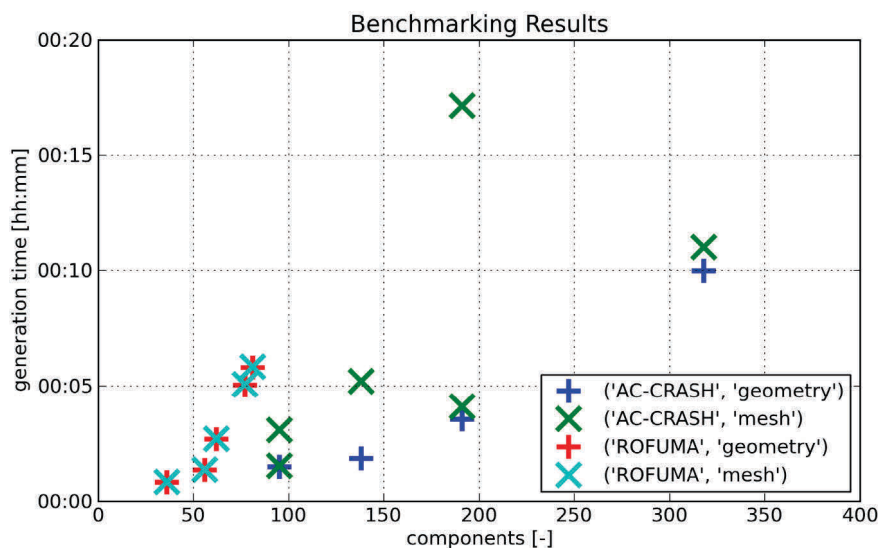


Figure 17: Benchmarking results for model generation

## 6. Conclusion and outlook

In this paper structural analysis methods for the preliminary design process of air- and rotorcraft were presented. The introduced processes start at the end of the conceptual design phase with a fuselage loft. Several tools were introduced for successive use.

At first, the primary structure is provided to the fuselage loft by the use of F-DESIGN. After this step, static analysis respectively static sizing due to flight and ground load cases is conducted using the tools TRAFUMO/ROFUMA and S-BOT+. Concluding the preliminary design stage a crashworthiness computation is conducted by the use of the tool AC-CRASH.

For all presented processes CPACS is used as centralized data format. Geometry description within CPACS has been described as well as basic modeling approaches during model generation. The versatility offered by CPACS has been highlighted by demonstrating its parametric approach.

A benchmarking analysis highlighted the speed of the presented modeling tools. Due to the parametrized and automated approach versatile models can be generated with little effort and within short time.

Concerning the various tools the following developments are desired:

- F-DESIGN will be unified as currently two versions exist – one for air- and one for rotorcraft. Future versions of F-DESIGN shall be able to not only generate new distributions of primary structures but also to alter already existing configurations.
- TRAFUMO: Future work will concern with generation of alternate wing integration concepts, for instance high wing and strut braced wing.
- ROFUMA will be modified in near future by integrating ELWIS to generate additional lift surfaces as given by compound helicopters. Moreover, ROFUMA will be integrated into S-BOT+ module to allow structural rotorcraft sizing.
- S-Bot+ is currently extended by a module based on analytical methods. These methods will provide an initial sizing with the objective to reduce the number of numerical iterations, thus, achieving faster convergence.

- AC-CRASH respectively X-CRASH are currently being extended to rotorcraft structures. Moreover, a further increase of detail level is desired.

General future development focuses on accelerating processes as well as data handling (for instance, result files of crashworthiness computations have already reached sizes of 20GB).

## 7. Acknowledgements

The author would like to gratefully acknowledge and appreciate the support by Dieter Kohlgrüber, Julian Scherer, Martin Siemann and Jan-Niclas Walther at DLR-BT.

Most of the work presented in this paper was achieved within the DLR-internal research project EDEN (Evaluation and Design of Novel Rotorcraft Concepts). The financial support herein is gratefully acknowledged.

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